PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference PCT2109AP071jdc	**FOR FURTHER ACTION** See Form PCT/IPEA/416	
International application No. PCT/EP2004/007386	International filing date *(day/month/year)* 06.07.2004	Priority date *(day/month/year)* 07.07.2003
International Patent Classification (IPC) or national classification and IPC H01S5/183		
Applicant AVALON PHOTONICS AG et al.		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 8 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 10 sheets, as follows:
      ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      ☒ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.
   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the opinion
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☐	Box No. VIII	Certain observations on the international application

Date of submission of the demand	Date of completion of this report
09.05.2005	07.10.2005
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Laenen, R Telephone No. +49 89 2399-6031

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/EP2004/007386

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

2, 4-7, 9-23	as originally filed
1, 1a, 3, 8	received on 09.05.2005 with letter of 09.05.2005

Claims, Numbers

1-29	received on 09.05.2005 with letter of 09.05.2005

Drawings, Sheets

1/9-9/9	as originally filed

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☒ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☒ the description, pages 3,8
   - ☒ the claims, Nos. 1,23
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No. PCT/EP2004/007386

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	10,11,14,15,17-19,21,22,24,27-29
	No:	Claims	1-9,12,13,16,20,23,25,26
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-29
Industrial applicability (IA)	Yes:	Claims	1-29
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. The following documents (D1-D5) are referred to in this communication; the numbering will be adhered to in the rest of the procedure:

D1: EP-A-0 772 266
D2: US-A-5 256 596
D3: SHINADA S ET AL: "Micro-aperture surface emitting laser for near field optical data storage" LASERS AND ELECTRO-OPTICS, 1999. CLEO/PACIFIC RIM '99. THE PACIFIC RIM CONFERENCE ON SEOUL, SOUTH KOREA 30 AUG.- 3 SEPT. 1999, PISCATAWAY, NJ, USA,IEEE, US, 30 August 1999 (1999-08-30), pages 618-619, XP010364559 ISBN: 0-7803-5661-6
D4: EP-A-1 276 188
D5: NISHIYAMA N ET AL: "MULTI-OXIDE LAYER STRUCTURE FOR SINGLE-MODE OPERATION IN VERTICAL-CAVITY SURFACE-EMITTING LASERS" IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE INC. NEW YORK, US, vol. 12, no. 6, June 2000 (2000-06), pages 606-609, XP000951817 ISSN: 1041-1135

2. Amendments filed with letter dated 09.05.2005 do not meet the requirements of Art. 34(2)(b) PCT.
Claims 1 and 23 comprise in addition to originally filed claims 1,23 the restriction of "so as to stabilize the fundamental lateral mode". Originally disclosed in the description of the application as filed is however only the restriction, that in the case of the "**first characteristic lateral size is greater than the second characteristic lateral size**" the fundamental mode with a **reduced gain for high order modes is preferentially supported.** As the latter features are missing in claims 1 and 23, the subject-matter of these claims extends beyond the disclosure as originally filed contrary to Art. 34(2)(b) PCT. Consequently the examination is based on originally filed claims 1,23 and claims 2-22,24-29 as filed with letter dated 09.05.2005.

3. Clarity objections.
Claims 1,2,4-9,15,16,19,20,23-29 lack clarity in the sense of Art. 6 PCT.
3.1 Claims 1 and 23 comprise the restriction of "so as to stabilize the fundamental lateral mode". This wording is however not allowable as only the result to be achieved is defined in said claims instead of stating device features (for example the relation of diameters of apertures) as would have been appropriate in this case (see International Preliminary Examination Guidelines 5.35).
3.2 In claims 27-29 characteristic **dimensions** are mentioned although in claims 23-26, to which these claims refer back, only a characteristic **lateral size** is defined. Therefore the "dimensions" are interpreted in terms of "lateral sizes".
3.3 Claims 1,2,4-9,15,16,19,23,25,26: The meaning of a "characteristic lateral size" is not clear as non-circular shaped apertures are also within the scope of the claims (see claim 21) which need at least two parameters to be defined in respect to their lateral size. To allow for an examination of said claims, the objected term is interpreted in terms of a "circular area defined by a characteristic diameter" (see Fig. 1e and claims 19,20 as well as the fact, that in all claims only **one** characteristic size is given and this is a clear hint towards a circular shape).
3.4 Claims 20,24,25 refer back to themselves leaving the claimed subject-matter unclear.
3.5 Claims 6 and 7 comprise the term "in the range of 6(4) µm". As it is however well known that a range has a starting and an end point, the scope of protection sought by said claims is completely unclear. In order to allow for examination of the subject-matter of said claims, said objected term is interpreted in terms of "in the range of 4 to 7 µm" (see claim 8).

4. The subject-matter of claims 1-9,12,13,16,19,20 is not new in the sense of Article 33 (2) PCT.

Document D1 is considered to represent the closest prior art.

4.1 D1 discloses a VCSEL 30 (Fig. 3) comprising
(I) a substrate with lower electrical contact 45 and second mirror stack 31 (Fig. 3; col.

5, l. 2-7; although not explicitly stated in D1 it is clear that a substrate must be present in order to be able to grow the layers cited in D1; electrical contacts are known to be made from metals);
(ii) a laser active region 32 (Fig. 3; col. 3, l. 30);
(iii) a first mirror stack 37 formed of alternating high and low index of refraction AlGaAs layers (Fig. 3; col. 3, l. 55-59; it is clear that these layers are doped in order to allow for a current flow); the first mirror stack comprising
(a) a first plurality of doped layers 39 having alternately low and high index of refraction (Fig. 2; col. 3, l. 31-54; note the layers below aperture layer 42), and two circular apertures,
(b) first circular aperture with diameter of about 23.5 μm is formed above said first plurality of layers by implanting 42 part of layers 39 (Figs. 2,3; col. 4, l. 27-30; it is well known that implantation results in electrical insulation and absorbance of laser radiation and implantation is a standard workshop alternative to for example oxidation of a layer to build an aperture; the diameter of about 23.5 μm is calculated from col. 3, l. 16-18 and col. 4, l. 56 - col. 5, l. 1 and Fig. 3);
© a second circular aperture is formed above said first plurality of layers by oxidation 38 part of layers 39 resulting in an aperture with a diameter smaller than the diameter of the mesa and diameter of the first aperture (Fig. 3; it is clear from the oxidation process that the oxidized Al-oxid is insulating and substantially non-transparent while the non-oxidized part is well-known to be transparent for the laser wavelength and conductive); and
(d) a second plurality of AlGaAs layers 37 forming a mesa with diameter of approximately 19.5 μm being smaller as the diameter of the first aperture of 23.5 μm and the diameter of the non-etched part of the plurality of mirror layers (see point 3.5 above; Fig. 3; see discussion in point (b) above), the difference of about 4 μm in diameters of the aperture and the mesa being adapted to generate increased optical losses of the resonator made up by mirrors 31,37 with respect to higher order modes for the laser wavelength compared to the losses by the aperture alone (col. 3, l. 16-18 and col. 4, l. 50 - col. 5, l. 1) which implicitly equals support of fundamental mode emission considering also the circular shapes of the apertures); and
(e) a radiation output window 44 above said first reflector formed by the circular aperture within electrical contact 43, the aperture having a smaller diameter as the mesa or the aperture layer 42 (Fig. 3; col. 5, l. 2-5; electrical contacts are known to be

made from metals; from the diameters defined in D1 it is clear that all apertures are circular; see point 3.3 above).

Therefore, the subject-matter of claims 1-9,12,13,16,19,20 is not new in the sense of Article 33 (2) PCT.

4.2 According to the wording of claim 1 the subject-matter of claim 1 is also known from D2 as D2 discloses a GaAs substrate 12 with a lower p-DBR mirror stack 14, an active zone 16 and an upper n-DBR mirror stack 18 with a buried Be Implant 27 leaving an aperture above part of the mirror layers and a mesa 25 with smaller diameter (Figs. 1,2; col. 2, l. 28 - col. 4, l. 12; an implant is the standard workshop alternative to oxidation of a layer in order to realize an aperture and implantation results in electrical insulation of the implanted region as well as absorbance of laser light) with the difference of the diameters of the mesa and the aperture being adapted for lowest order mode lasing (col. 3, l. 37-62; this equals fundamental mode lasing).

5. The subject-matter of claims 23,25,26 is not new in the sense of Article 33 (2) PCT.

Document D1 is considered to represent the closest prior art.

D1 discloses a method of forming a VCSEL comprising the steps of
selecting together with a laser wavelength appropriate semiconductor materials for first and second DBR mirror (the use of AlGaAs DBR clearly indicates a laser wavelength around 800 nm as well known to the skilled person);
determining an aperture diameter equal to the minimum acceptable diameter of the aperture formed by oxidation of AlGaAs layers (col. 3, l. 1-41);
choosing the diameter of the mesa depending on the size of the aperture and the operation of the laser in the basic mode (col. 4, l. 50 - col. 5, l. 1);
forming the active region and the output window according to the dimensions given from the diameter of the aperture of about 23.5 µm and the mesa of 19.5 µm (see points 3.3 and 4.1 above for references).

Therefore, the subject-matter of claims 23,25,26 is not new in the sense of Article 33 (2)

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6. Dependent claims 10,11,14,15,17,18,21,22,24,27-29 do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements of the PCT with respect to inventive step, the reasons being as follows:
Any number of doped layers in a DBR is obvious to grow depending on the desired reflectivity, contacting above the active layer is an obvious alternative to contacting the substrate, an aperture smaller than the mesa is known form D2 (Fig. 3), phase-matching layers above the upper DBR are known from D3 (Fig. 1), non-circular shaped apertures or windows are known from D4 for polarization control (Fig. 5; par. 20,21,33-37).
Calculations of the optical and electrical field distribution within VCSEL are well-known and therefore obvious for the skilled person to optimize the design of a VCSEL in respect to laser threshold, polarization control and fundamental mode operation (see D3 and D5 and point 3.1 above). From these calculations automatically margins for characteristic diameters are inferred and therefore obvious.

International Patent Application No. PCT/EP2004/007386
Applicant: AVALON PHOTONICS AG
PCT2109AP071ter
May 9, 2005

NEW CLAIMS

1. Vertical cavity surface emitting laser comprising:

a laser active region (140), a resonator having a first reflector (110) and a second reflector (130),

the first reflector (110) comprising

a first plurality of doped layers (111) having alternately a low index of refraction and a high index of refraction,

an aperture layer (112) located above said first plurality of doped layers (111) and formed of an insulating material that is substantially non-transparent for a specified wavelength range, the aperture layer (112) having an aperture (113) formed of conductive and optically transparent material with a first characteristic lateral size (d_{ox}), and

a second plurality of doped layers (114) having alternately a low Index of refraction and a high Index of refraction, the second plurality (114) having a second characteristic lateral size (dm), a difference (117) of the first characteristic lateral size (d_{ox}), and

the second characteristic lateral size (d_m) being adapted to generate increased optical losses of said resonator with respect to higher order modes for said specified wavelength range compared to the optical losses caused by said aperture layer alone so as to stabilize the fundamental lateral radiation mode, and

a radiation output window (150) formed above said first reflector (110) or below said second reflector (130).

2. The vertical cavity surface emitting laser of claim 1, wherein said radiation output window has a third characteristic lateral size that is less than the first and the second characteristic lateral sizes.

3. The vertical cavity surface emitting laser of claim 1 or 2, wherein said radiation output window is formed in a metal layer.

4. The vertical cavity surface emitting laser of any of claims 1 to 3, wherein said first characteristic lateral size is equal to or greater than 5 µm.

5. The vertical cavity surface emitting laser of claim 4, wherein said first characteristic lateral size is equal to or greater than 6 µm.

6. The vertical cavity surface emitting laser of any of claims 1 to 5, wherein an absolute amount of said difference of the first characteristic lateral size and the second characteristic maximum lateral size is in the range of 6 µm.

7. The vertical cavity surface emitting laser of any of claims 1 to 5, wherein an absolute amount of said difference of the first characteristic lateral size and the second characteristic maximum lateral size is in the range of 4 µm.

8. The vertical cavity surface emitting laser of any of claims 2 to 7, wherein said third characteristic lateral size is in the range of 4 to 7 µm.

9. The vertical cavity surface emitting laser of any of claims 1 to 8, further comprising a third plurality of doped layers having alternately a low index of refraction and a high index of

refraction, the third plurality of doped layers being disposed between said aperture layer and said second plurality of doped layers and having a characteristic lateral size that is greater than said second characteristic size.

10. The vertical cavity surface emitting laser of any of claims 1 to 9, wherein the number of doped layers in said first plurality is equal to or less than 9.

11. The vertical cavity surface emitting laser of claim 9, wherein the number of doped layers in said third plurality is equal to or less than 9.

12. The vertical cavity surface emitting laser of any of claims 1 to 11, wherein said second reflector comprises a plurality of doped layers having alternately a low index of refraction and a high index of refraction.

13. The vertical cavity surface-emitting laser of claim 12, further comprising a substrate carrying said second reflector on one surface and a metal layer formed on the opposite surface of the substrate.

14. The vertical cavity surface emitting laser of any of claims 1 to 12, further comprising a contact layer formed between said laser active region and at least a portion of said second reflector, said contact layer being configured to electrically connect said active region to a contact pad.

15. The vertical cavity surface emitting laser of any of claims 1 to 14, wherein said first characteristic lateral size is equal to or less than said second characteristic lateral size.

16. The vertical cavity surface emitting laser of any of claims 1 to 14, wherein said first characteristic lateral size is greater than said second characteristic lateral size.

17. The vertical cavity surface emitting laser of any of claims 1 to 16, further comprising a phase matching layer formed within said resonator, the phase matching being configured to shape the transverse reflectivity of said resonator so as to suppress higher transverse radiation modes.

18. The vertical cavity surface emitting laser of claim 17, wherein said phase matching layer is provided above said second plurality of doped layers.

19. The vertical cavity surface emitting laser of any of claims 1 to 18, wherein said

aperture and said second plurality of doped layers have a substantially circular shape and said first and second characteristic lateral sizes represent a first diameter and a second diameter, respectively.

20. The vertical cavity surface emitting laser of claim 20, wherein said radiation output window has a substantially circular shape.

21. The vertical cavity surface emitting laser of any of claims 1 to 19, wherein at least one of said aperture and said second plurality of doped layers has a non-circular shape to provide different optical losses for different polarization states of a low-order radiation mode of said specified wavelength range.

22. The vertical cavity surface emitting laser of any of claims 20 or 21 wherein said radiation output window has a non-circular shape to provide different optical losses for different polarization

states of a low-order radiation mode of said specified wavelength range.

23. A method of forming a vertical cavity surface emitting laser, the method comprising:

selecting a target output wavelength range,

selecting appropriate semiconductive materials for a laser active region and a first and second reflector, wherein the first reflector includes a first plurality of doped layers and a second plurality of doped layers with an aperture layer arranged therebetween,

determining a minimum acceptable lateral size of an aperture formed in said aperture layer,

correlating at least two of the following characteristic dimensions of the vertical cavity surface emitting laser, a first characteristic lateral size representing a lateral extension of said aperture, a second characteristic lateral size representing a lateral extension of said second plurality of doped layers, a third characteristic lateral size representing a lateral size of a radiation output window, a vertical distance between said laser active region and said aperture layer and a vertical distance between said aperture layer and said second plurality of doped layers, so as to increase optical losses of higher radiation modes than are obtained with said minimum acceptable lateral size alone so as to stabilize the fundamental lateral radiation mode, wherein said first characteristic lateral size is equal to or higher than said minimum acceptable lateral size, and

forming said laser active region, said first and second reflectors and said radiation output window according to dimensions determined during said correlating step.

24. The method of claim 24, wherein said minimum acceptable lateral size is selected so as to maintain a current density below a critical threshold for an output power of 1 mWatt and more.

25. The method of claim 25, wherein said minimum acceptable lateral size is 5μm or more.

26. The method of claim 25, wherein said minimum acceptable lateral size is 6μm or more.

27. The method of any of claims 24 to 26 wherein correlating at least two characteristic dimensions includes:

varying one or more of the characteristic dimensions while keeping at least one characteristic dimension constant, and

determining at least one of an output power and an output wavelength for a specified operating range.

28. The method of claim 24, wherein correlating at least two characteristic dimensions includes calculating an optical field within said resonator for a plurality of value combinations and determining a design value range for at least one of the at least two characteristic dimensions for at least one of a desired output power and a spectral purity.

29. The method of claim 24, further comprising specifying process margins for said at least two characteristic dimensions on the basis of said correlation.

A VERTICAL CAVITY SURFACE EMITTING LASER HAVING IMPROVED TRANSVERSE MODE CONTROL AND A METHOD OF FORMING THE SAME

The present invention generally relates to vertical cavity surface emitting lasers (VCSEL) comprising a first reflector and a second reflector to define a resonator, wherein a laser active region is located between the first and the second reflector. Moreover, the VCSEL under consideration includes an aperture layer so as to control optical losses of higher-order transverse radiation modes, thereby providing a single transverse mode emission or emission with a reduced output wavelength range.

VCSEL devices of the kind described above are known from documents EP-A-0772266, US-A-5 256 596 and SHINADA S ET AL: „Micro-aperture surface emitting laser for near field optical data storage" LASERS AND ELECTRO-OPTICS, 1999. CLEO/PACIFIC RIM '99. THE PACIFIC RIM CONFERENCE ON SEOUL, SOUTH KOREA 30 AUG. –3 SEPT. 1999, PISCATAWAY, NJ, USA, IEEE, US, 30 August 1999 (1999-08-03), pages 618-619, XP010364559 ISBN: 0-7803-5661-6.

VCSEL devices are considered an attractive alternative to conventional double-heterostructure laser diodes due to their small size and their potentiality of being formed in a substantially circular symmetry. Generally, VCSEL devices show a relatively low threshold current, a high modulation efficiency and, if designed so as to emit a substantially circular beam profile, allow to be coupled into optical fibers in a simple fashion. Additionally, the manufacture of VCSEL devices comes along with a parallel and cost-effective production, testing and packaging process, and also offers the possibility of being packed densely in one and two-dimensional arrays to comply with a plurality of applications such as data communication, sensing applications, and the like.

VCSEL devices inherently operate in a single longitudinal radiation mode due to their short cavity length. On the other hand, typically a plurality of transverse radiation modes are simultaneously present within the resonator, wherein the spectral purity, i.e., the number, width and intensity of wavelengths being present in the output radiation, is substantially defined by the lateral geometry of the VCSEL device. It appears, however, that in certain applications it is important to provide a high spectral purity or a substantially monochromatic emission, such as in spectroscopy applications. A substantially single mode emission, that is, emission of a single longitudinal and transverse radiation mode, is also highly desirable for applications such as positioning, laser printing, or short distance optical interconnections. In a typical VCSEL device having a multimode radiation behavior, an increased transverse mode competition may be observed as the drive current increases, resulting in unstable, non-symmetric, and large divergence angle beam profiles. The multimode behavior entails a plurality of

According to one aspect of the present invention, the object is solved by a VCSEL device that comprises a laser active region and a resonator having a first reflector and a second reflector. The first reflector comprises a first plurality of doped layers having alternately a low index of refraction and a high refraction. The first reflector further comprises an aperture layer located above the first plurality of doped layers and formed of an insulating material that is substantially non-transparent for a specified wavelength range, wherein the aperture layer has an aperture with a first characteristic lateral size. The first reflector further includes a second plurality of doped layers having alternately a low index of refraction and a high index of refraction, wherein the second plurality of doped layers has a second characteristic lateral size, whereby a difference of the first characteristic lateral size and the second characteristic lateral size is ~~adjusted so as~~ adapted to generate increased optical losses of the first reflector with respect to higher transverse radiation modes for the specified wavelength range compared to the optical losses created by the aperture layer, also so as to stabilize the fundamental lateral radiation mode. Additionally, the VCSEL device comprises a radiation output window that is formed above the first reflector or below the second reflector.

The VCSEL device in accordance with the present invention has a design in which the lateral confinement of the optical field is determined by the interaction of the aperture and the lateral dimension of a portion of the first reflector rather than by an oxide aperture alone. Due to the combined effect of the first and second characteristic lateral sizes the optical losses of the higher order radiation modes are higher compared to the effect of the aperture alone so that the lateral size thereof may be increased compared to conventional approaches without compromising the single mode emission behavior of the VCSEL device. Consequently, the current density through the aperture, and hence through the laser active region, is decreased, thereby significantly increasing the reliability and lifetime of the VCSEL device for a specified required output power. A further advantage resides in the fact that the operating behavior of the VCSEL device is substantially determined by lateral dimensions of the device so that the required device behavior may be adjusted in a simple and cost-efficient manner during manufacturing of the device. Moreover, since the device behavior is significantly influenced and thus in a high degree determined by at least two device dimensions, a deviation of one dimension during the manufacturing process may be compensated for, at least partially, by adjusting the other one of the characteristic lateral sizes in correspondence with the

In a further embodiment, the VCSEL device comprises a phase matching layer arrange within the resonator, wherein the phase matching layer is configured to laterally pattern the reflectivity of the resonator. Preferably, an optical thickness of the phase matching layer is adapted so as to provide an increased reflectivity at lateral positions with a high probability for the fundamental mode and a low reflectivity at positions of increased amplitudes of the higher-order modes. With the provision of the phase matching layer, which defines a further characteristic lateral dimension regarding the mode confinement and mode selectivity, the performance of the device may further be enhanced and may allow an increased aperture size without significantly compromising the device behavior.

According to another aspect of the present invention, a method of forming a vertical cavity surface emitting laser comprises selecting a target output wavelength range and selecting appropriate semiconductive materials for a laser active region and a first and second reflector, wherein the first reflector includes a first plurality of doped layers and a second plurality of doped layers having a lateral size less than that of the first plurality of doped layers, with an aperture layer arranged between the first and second pluralities of doped layers. Furthermore, a minimum acceptable lateral size of an aperture formed in the aperture layer is determined. Then, at least two of the following characteristic dimensions of the VCSEL device, that is: a first characteristic lateral size representing a lateral extension of the aperture, a second characteristic lateral size representing a lateral extension of the second plurality of doped layers, a third characteristic lateral size representing a lateral size of a radiation output window, a vertical distance between the laser active region and the aperture layer, and a vertical distance between the aperture layer and the second plurality of doped layers, are correlated to each other to increase optical losses of higher-order radiation modes compared to the optical losses created by an aperture alone that has the minimum acceptable lateral size <> wherein the first characteristic lateral size, i.e. the size of the aperture, is equal to or greater than the minimum determined acceptable lateral size. Finally, the laser active region, the first and second reflectors, and the radiation output window are formed according to dimensions determined by the correlating step.

<so as to stabilize the fundamental lateral mode>